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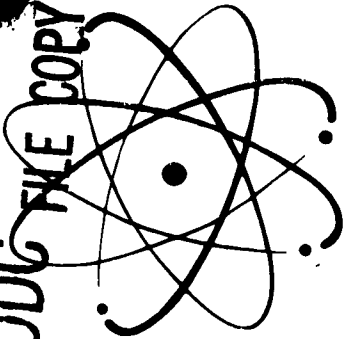# UNCLASSIFIED

INTERIM TECHNICAL REPORT

on the

RESEARCH, DEVELOPMENT, AND FABRICATION

OF TUNNEL EMISSION CATHODES

Contract No. DA-49-186-ORD-1053

SECOND QUARTERLY REPORT

Covering the period October through December, 1962

For

HARRY DIAMOND LABORATORIES

WASHINGTON, D. C.

RECEIVING TUBE DEPARTMENT

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For

HARRY DIAMOND LABORATORIES

WASHINGTON, D. C.

(10) by   Prepared: C. E. Horton, and

J. W. Hall, IL

Approved: A. P. Haase

Receiving Tube Department
General Electric
Owensboro, Kentucky

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PURPOSE

The objectives of the work being performed under this contract are to develop a better theoretical understanding of the tunnel cathode, to evaluate both materials and processes for the fabrication of this type of device, and thereby to develop a tunnel cathode having desirable electrical and mechanical characteristics.

Efforts were continued on the development of materials and processes for the fabrication of tunnel cathodes.

ABSTRACT

Approximately the first half of this quarter was devoted (1) to solving vacuum system problems that developed without warning *were solved* and ~~to making~~ major improvements in the vacuum system *were made* in order to obtain much better vacuum conditions during the deposition of metal films. As a result of these and other changes, it ~~has been~~ *was* possible to make insulating films of high current-carrying capacity with reassuring regularity.

During the second half of the quarter a series of tests was made to determine the effects of substrate temperature, evaporation rate, accelerator material, and other variables. ~~Most of these tests resulted in uniformly good experimental results, indicating that most of these variables are not extremely critical over the range covered by the tests and also showing that a more critical test method is required if film processing techniques are to be optimized.~~

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MEETINGS AND CONFERENCES

J. W. Hall, II and C. E. Horton made the following contacts on a trip to the west coast:

1. Varian Associates, Vacuum Products Division, Palo Alto, California, October 29, 1962. Discussion of vacuum systems and techniques.

2. K. R. Shoulders, Stanford Research Institute, Menlo Park, California, October 29, 1962. Brief discussion of his published work on micro-miniature field emission tubes and ideas on vacuum techniques and thin-film devices.

3. Ultek Corporation, Palo Alto, California, October 30, 1962. Discussion of our vacuum system problems and specific short-range and long-range solutions. General discussion of vacuum equipment and techniques.

4. Dr. C. A. Mead, California Institute of Technology, Pasadena, California, October 31, 1962. Consultation on his work on tunnel cathodes and on his interpretation of experimental results. We also discussed some of our current problems.

5. American Vacuum Society - Ninth National Symposium, Los Angeles, California, October 31 - November 2, 1962.

CORRECTION OF VACUUM SYSTEM PROBLEMS

A. The Nature of the Problems

Experimental work on this project was interrupted by a sudden rise in the vacuum system pressure on October 1. Diagnosis and correction of the difficulty, which proved to be a leak, was very time consuming. Complicating the symptoms was the appearance during the course of this work of electrical leakage in the ion pump.

The difficulty with the vacuum system brought into sharper focus another question that had been under study for several weeks: Did our existing vacuum system fully meet the exacting requirements of our thin film work? During the month of September, to make our vapor depositions at the pressures we felt were needed, we were painstakingly operating or attempting to operate at the best pressure levels the system could provide. Our results strongly suggested, but did not prove, that these low system pressures are important. Discussions with others working on thin film tunnel cathodes, particularly Dr. L. A. Harris of the General Electric Research Laboratory and Dr. C. A. Mead of the California Institute of Technology, supported the conclusion that the pressures necessary for our thin film work are lower than we had originally supposed.

B. System Modifications

On the basis of this information, we obtained a company appropriation to provide for whatever vacuum system modifications were needed for successful thin film work. The specific changes contemplated at that time were:

1. The replacement of the 90 liter ion pump with a 400 liter pump.

2. The addition of an Ultek Boostivac unit with a larger baseplate.

3. The purchase of enough parts so that with the 90 liter pump and original baseplate a second vacuum system could be constructed.

As a first step, the 400 liter pump and a new roughing manifold were ordered. As anticipated, the higher pumping speed appeared to help in two ways: The pressure corresponding to a given rate of gas evolution was lower; and, because more gas was being removed, the rate of gas evolution from the system was lower after a few hours of pumping.

A new roughing manifold was added, and this also appeared to be a substantial improvement. Previously, each of the sorption pumps was connected directly to the system through about a foot of 1" tubing and a 1" high vacuum valve. A third 1" valve, the up-to-air valve, was also connected directly to the high vacuum system. The 1" tubing was not easy to bake out without overheating the valves and seemed to be an undesirable gas source. With the new manifold, the high-vacuum side of the system sees only one 1" valve and a very short length of 1" tubing. This is probably a contributing factor towards cleaner system. Also, it is now both possible and convenient to bake out one of the sorption pumps into the other. With one of the sorption pumps thus kept clean and gas-free by occasional baking, the system may be roughed down to pressures as low as a micron before starting the ion pump. In general, the new manifold makes the vacuum system easier to operate as well as improving its performance.

The procedure of baking the system overnight has been followed religiously, and the resulting difference in performance is more noticeable since the modifications were made in the system than it was before. The pump itself requires bake out as much as any other part of the system. The system in its present form is shown in Figure 1.

C. Brief History

The entire procedure described above involved, when the leak first appeared, taking pressure rise curves on the system and helium leak testing. A leak was definitely indicated, but all that could be said about its location was that it was below the main valve. The lower part of the system was taken apart and reassembled using new shear seals. The system pressure reading indicated that a leak was again present, but we decided not to take the extra day required for making another pressure rise curve. In retrospect it appears that the difficulty we saw was a combination of ion pump leakage (ion pump current is used to monitor system pressure) and outgassing of parts that had been exposed to the
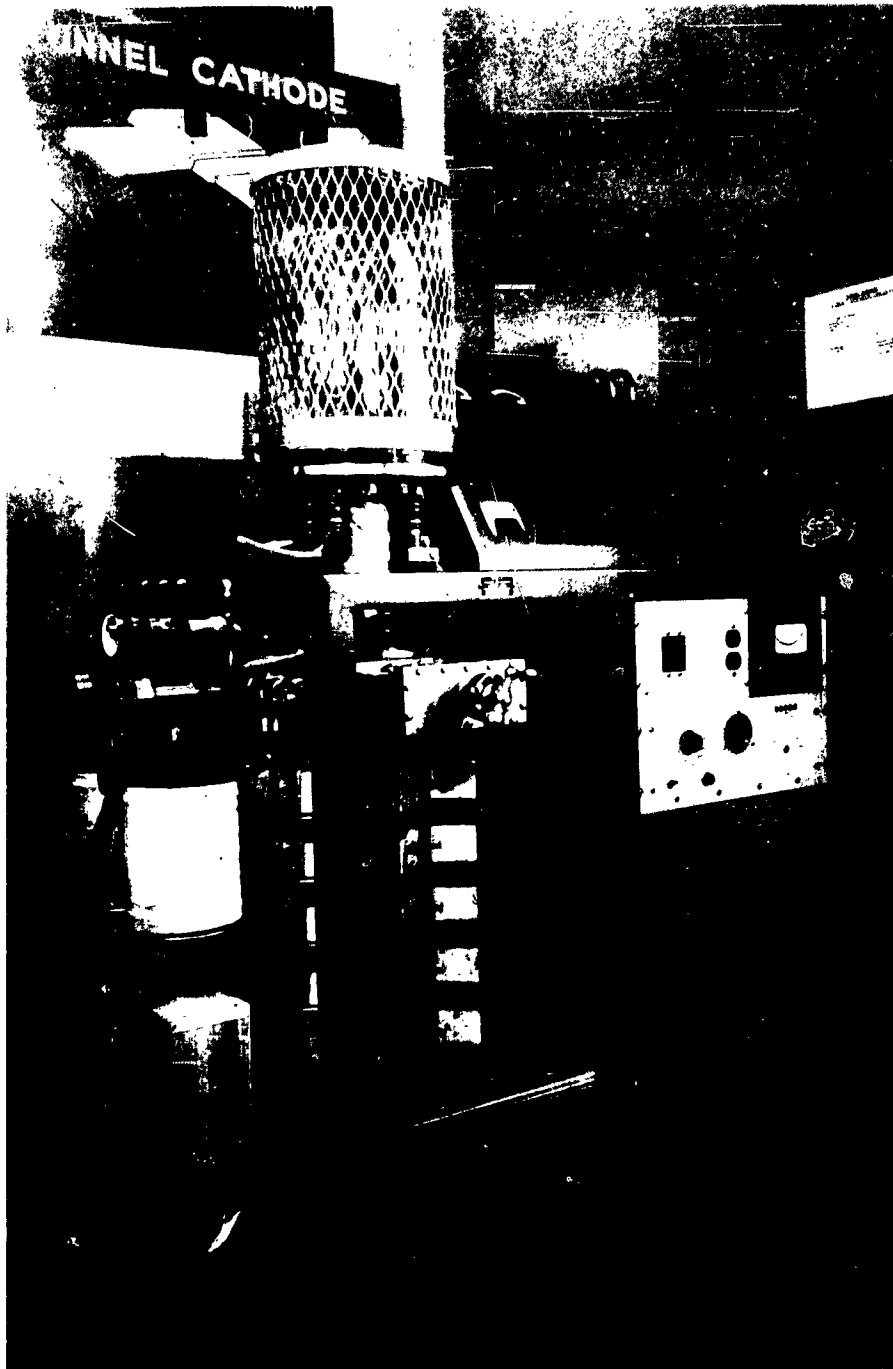
Figure 1

Ion Pump Vacuum System as Modified

atomsphere. The equipment was disassembled and the shear seals and seal flanges were carefully checked for dimensional accuracy. The ion pump leakage was discovered and corrected.

At this point, the decision to order the larger pump was made. Since delivery of the pump was expected in a few days, the system was not reassembled. Unfortunately a mishap during pre-shipment bake out of the only two pumps available at the time caused a considerable delay in shipping. The pump was received on Monday, November 12. The system was assembled and successfully put under vacuum the same day. After work on the manifold and bake out of the system, it was used for film deposition work on Friday, November 18.

D. Results Obtained

The first units made in the modified system yielded higher film currents than had been obtained in any of the test units made under the contract up to that time. Since then, high current densities have been consistently obtainable, and vacuum conditions no longer appear to be a problem.

We have closely watched the effect on the electrical test results of the system pressure during aluminum deposition, and we were surprised to find that films of good quality were obtained at pressure levels that we had previously regarded as too high for satisfactory results.

E. Use of Oil System

The apparent inconsistencies in the importance of vacuum conditions prompted a radical departure from our philosophy on this point, and we tried depositing the gold accelerator layers in a vacuum system using an oil diffusion pump. We used a standard CEC bell jar system capable of an ultimate pressure of about 10^{-5} torr. The system is not trapped; therefore, a certain amount of oil contamination is to be expected. To date our test results have failed to show that accelerator films made in this way are any less successful than films deposited in the ion system.*

This surprising result has been used to good advantage. With the ion pump system used exclusively for deposition of aluminum emitter films and the oil system used for gold accelerators, much less setup time is needed. The ion pump system probably remains appreciably cleaner because of the simplicity of the operations carried out in it.

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* Third quarter test results show that the oil system can have a detrimental effect.

F. Explanation of Results

The following satisfactorily explains the observed facts and is regarded
as a tentative conclusion based on our thin film experience to date.*

The accelerator film is insensitive to contamination (at least insofar as
our present test methods are able to distinguish), probably for several reasons:
First, because gold is chemically inactive, the gasses striking the freshly-formed
film will have less tendency to stick to it than they would to an active metal
like aluminum; consequently, fewer impurities will be picked up. Second, the
acclerator film properties are less critical because its structure has little or
no effect on the structure of the insulating film. A high degree of uniformity
is probably not a requirement. Third, it is not subjected to the anodizing
bath and thereby avoids one of the problems encountered with the emitter layer.

By contrast, the emitter film must be deposited under very clean vacuum
conditions. In the extreme case, i.e., in an untrapped oil system, contamination
results in a weak film-to-substrate bond that is easily broken as a resulᵤ of
electrochemical effects associated with anodizing. Peeling of the film or some
other type of gross defect is likely. With a lower level of contamination,
film buildup may be inhibited in some spots, with the result that the film has
pinholes. Whatever the mechanism, contamination from the vacuum system that
is used to deposit the emitter decreases the current-carrying capacity of the
resulting oxide insulating film, probably by decreasing its uniformity.

The gasses and vapors in the vacuum system after it has had a chance to
pump down may be thought of as belonging to one of four categories:

1. Materials evolved from the walls of the system
    and other surfaces before deposition of the metal
    film.

2. Materials evolved from the walls of the system
    and other surfaces (including the surfaces of the
    electrodes) during film deposition.

3. Materials evolved from the metal being deposited.

4. Gasses admitted to the system through leaks.

Harmful effects seem to be associated with sources 1 and 2. The first
would result in substrate contamination and develop an unsatisfactory foundation
for a uniform film. The second would produce contamination in or on the film

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*Tests made during the third quarter strongly support the conclusions drawn here.

itself. These sources are strongly correlated, and distinguishing between them would be difficult. In the absence of leaks, a high ultimate system pressure suggests a reservoir of loosely-bound gas. During metal deposition, this gas will be readily released by radiation heating (and by direct heating in the case of the electrode surfaces) and by mechanical shock as the evaporating metal atoms strike gas molecules adsorbed on the exposed surfaces.

In our experiments, sources 3 and 4 appear not to be detrimental. Most of the gases evolved from the aluminum will have little tendency to react with the freshly-formed film. (The gas evolved consists largely of nitrogen. Gasses forming stable compounds with aluminum would have little tendency to be released from the molten aluminum). The boat or wire used to supply heat is made of a refractory metal that is readily outgassed. Leaks are very small as evidenced by the low ultimate pressure of the system.

One of the specific indications that the above is true is that the films obtained during this quarter were consistently better than those made during the first quarter even though the ratio of system pressure to deposition rate was sometimes poorer. The significant factor seems to be that the ultimate pressure - the variable that a mass spectroscopist would call "background" - is consistently better. We believe that this means we now have a cleaner vacuum. Tests with a partial pressure analyzer are planned later in the project to determine what is meant in our case by "clean".

G. Summary of Essential Techniques

Based on this reasoning, the techniques used to produce satisfactory conditions for the deposition of aluminum emitter films are the following: First, the entire system is given a regular overnight bake out. Because of practical limitations, this bakeout is fairly light. Among the hottest parts of the system are the substrates themselves, at a temperature of about 150 C. Second, only carefully-cleaned parts are permitted inside the vacuum system. Handling of such parts is kept at a minimum, and is done only with tweezers or clean nylon gloves. Third, the only materials placed inside the vacuum system are those that have low vapor pressures. Brass, cadmium plated clips, and plastics of all kinds are among the outlawed materials. Fourth, the electrodes used to hold the metal vapor source are of heavy, high conductivity copper.

These will remain relatively cool during metal deposition and will therefore have less tendency to evolve gas at this critical time. Fifth, the system fixtures are designed to minimize the total area of concealed surfaces or volumes that might be difficult to outgas. This means, for instance, that such things as electrodes and shields are constructed with a minimum number of separate parts and that holes are drilled to let gas escape readily from blind screw holes.

H. Status of Additional Improvements

Two additional improvements - the addition of a Boostivac unit to the present vacuum system and the construction of a second ion system using our original 90 liter pump were planned. At present, there is no evidence to indicate the desirability of these changes. These changes will be made when and if the need for them is demonstrated.

The Boostivac unit would provide for a greatly increased pumping speed and enable pressures near 10^{-9} torr to be reached much more quickly than at present. However, high pumping speed and low pressure are not considered satisfactory substitutes for a clean system. All indications are that a good bake out on each pump-down cycle is an important procedure, and the present pump capacity is sufficient to produce low background pressures in this manner.

The need for a second ion system is lessened by the apparent success of the oil system for certain processing steps. Future requirements will determine the ultimate status of this system.

INVESTIGATION OF FILM PROCESSING METHODS AND MATERIALS

A. Objectives

The end of the first quarter saw an abrupt improvement in the electrical properties of the thin-film sandwiches being made for test purposes. Two major objectives of the second quarter were to identify the factor or factors associated with this improvement and to make possible further improvements in film quality. As already stated in the preceeding section, these objectives were both hindered and helped as a result of the vacuum system problems that arose at the beginning of the second quarter - hindered because of the substantial delay involved and helped because the vacuum system was, after this period of delay, much better equipped to produce the conditions that appear to be necessary for deposition of good films.

B. Test Criteria

In this work the criterion of film quality has been the film current density, i.e., the amount of current that can pass through the insulating film before burnout occurs, using a rectified 60-cycle voltage source. The use of this criterion is based on the supposition that burnout at low currents indicates nonuniformities in the film, probably in the form of thin spots that cause high concentrations of current flow and ultimately result in thermal damage. This means of measuring film quality was extremely useful during the first quarter because of the relative convenience of this type of measurement and because the film quality was such that variations in maximum film current were observed. During the second quarter a large number of the films sustained currents very close to the highest currents that have been obtained. This interfered with determining the effects of some variables, and it indicates that more sensitive tests of film quality are now required. Additional discussion of this point will be found in parts I and J of this section.

C. Effect of Anodizing Current Density

The rate of formation of the aluminum oxide insulator film from the aluminum emitter layer is determined by the current density that is drawn during the anodizing process. Variations in this rate would be expected to have some effect on the structure of the insulating layer and therefore upon its electrical properties. One of the changes made at the end of the first quarter was a lowering of the anodizing current; therefore, this factor was investigated to see whether it was partly responsible for the good results that were obtained.

Aluminum films were anodized at current densities of 30, 60, 105, and 150 microamperes per square centimeter (the highest of these figures corresponds to the current density normally used); however, the data failed to show any really significant differences in performance as the anodizing current was changed. Data on one lot (#58) showed that with aluminum accelerators the units that were anodized at 30 $\mu a/cm^2$ were nearly all shorted out initially. This suggests that very low current densities may be undesirable; but, since the results obtained with aluminum accelerators were in general poor, we do not feel justified in drawing definite conclusions on the effect of anodizing current density.

D. Comparison of Anodized and Thermal Oxides

Oxide layers were prepared by exposing the aluminum films to various combinations of oxidizing atmospheres and film temperatures. In general, it was found less difficult than had been expected to achieve film thicknesses corresponding to tunneling voltages as high as four volts. The knee of the E-I characteristic, typically quite sharp for good anodized films, was much more rounded for the films grown in oxygen or air atmospheres. Tentatively, we interpret this to mean that the insulating films are not uniform in thickness, and that we have therefore sacrificed one of the inherent advantages of anodization.

Nevertheless, there are indications that these films may be capable of excellent stability under the applied electrical stress. The best results were obtained on one slide of lot 69. All twenty units on this slide sustained 200 milliamperes at 4 volts before burnout occurred. These units had been oxidized at 60 C in air for one hour and in oxygen for 3 1/2 hours.

E. Effect of Accelerator Material

Four different accelerator materials, Ag, Au, Al, and Pt, were selected for comparative tests on the effect of this variable. We were not successful in obtaining satisfactory evaporated films of platinum. Tests on the other materials showed that the insulating film has the best electrical properties when a gold accelerator film is deposited on it.

Silver accelerator films deposited on aluminum that has been oxidized thermally have the most striking effect on the insulating films. The voltage just above the knee in the I-V characteristic is about 1.5 volts as compared to 6 volts for gold electrodes on the same insulating film. The units have a high current-carrying capacity, about 25 amps/cm^2, and they can sustain this current for several seconds before burnout occurs. The knee of the I-V characteristic is much more rounded than it is with gold accelerators.

Lots 70-73, the last made during this quarter, included four slides prepared by depositing silver on anodized films. These units showed that the knee of the silver units was sharp and was at six volts (as compared to seven volts with gold). However, the silver deposit was lighter than intended, and three of the slides gave only very erratic test results. On the fourth, all of the units failed at very low currents. Because of the uncertainty as to how these results should be interpreted, the compatibility of silver accelerators with anodized aluminum films must still be regarded as unknown.

Units made with aluminum accelerators will, in general, operate at about the same voltage as those made with gold accelerators; but their current-carrying capacity is much less. Figure 2 shows, among other things, data on two lots of test units, nos. 60 and 61, in which both gold and aluminum accelerators were laid down on common emitter and insulator layers. As shown by the data on gold accelerators, these insulating films are capable of supporting substantial currents; however, with aluminum accelerators this capacity is greatly reduced.

A short explanation of the type of data presented in Figure 2 should be made. Each lot consists of four microscope slide substrates and a total of eighty thin-film sandwiches suitable for test. Except for an occasional unit that is mechanically damaged (for instance,

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A short explanation of the type of data presented in Figure 2 should be made. Each lot consists of four microscope slide substrates and a total of eighty thin-film sandwiches suitable for test. Except for an occasional unit that is mechanically damaged (for instance,

it might be accidentally scratched by the tip of the soldering iron when the indium contact terminals are applied), all eighty of these are subjected to electrical test. Some of the units may be initially shorted, i.e., they have a low, linear resistance; and no voltage threshold is seen before the onset of current flow. Others may be initially open circuited. These defects are recorded. The operable units show I-V characteristics that suggest current flow by tunneling electrons. A number of the units are operated at high current levels to determine the burnout current, and these currents are recorded in Figure 2. The remaining operable units are not recorded in Figure 2 because their current-carrying capacity is as yet undetermined. The original data also include the voltage at which the units operate, plus comments on the shape of the I-V characteristic.

The readings made on individual junctions were grouped for ease of presentation. Thus, a check in the 100 ma column means that a test unit burned out at a current that was between 87.5 ma and 112.5 ma. The zero ma column corresponds to a burnout current that is less than 12.5 ma. Where an excessive number of checks would be required, a number is written instead; for example, in the lot 60 data, the number 35 indicates that 35 tubes burned out at less than 12.5 ma.

As mentioned earlier, the data were taken using a rectified 60-cycle voltage source. The I-V characteristic is observed on an oscilloscope. Burnout current is measured with the current increased fairly rapidly. This is done manually; and typically, the time for which the current exceeds 100 ma is less than a second. Repeatability of results is fairly good as evidenced by the reasonably close bunching of points on the charts of Figure 2; however, variations in the rate at which the current is increased throw a certain amount of uncertainty into the data.

Other test lots show that aluminum accelerators are capable of better performance than Figure 2 suggests. For instance, in lot 58, currents of 100, 100, and 150 ma were measured on units with aluminum accelerators; however, most of the other units in lot 58 had very low current-carrying capacity.

No explanation for these results will be proposed. Our results appear to be inconsistent with those of Handy[1], who finds that aluminum, silver, and

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[1] R. M. Handy, Electrode Effects on Aluminum Oxide Tunnel Junctions, Phys. Rev., 126, pp. 1968-1973, June 15, 1962.

0   25   50   75   100 125 150 175 200 275

Lot 60
(Al)

21   35   x

Lot 61
(Al)

x   x   35   x

Lot 60
(Au)

13

Lot 61
(Au)

Lot 64
(Au)

x

Short Open   0   25   50   75   100 125 150 175 200 225
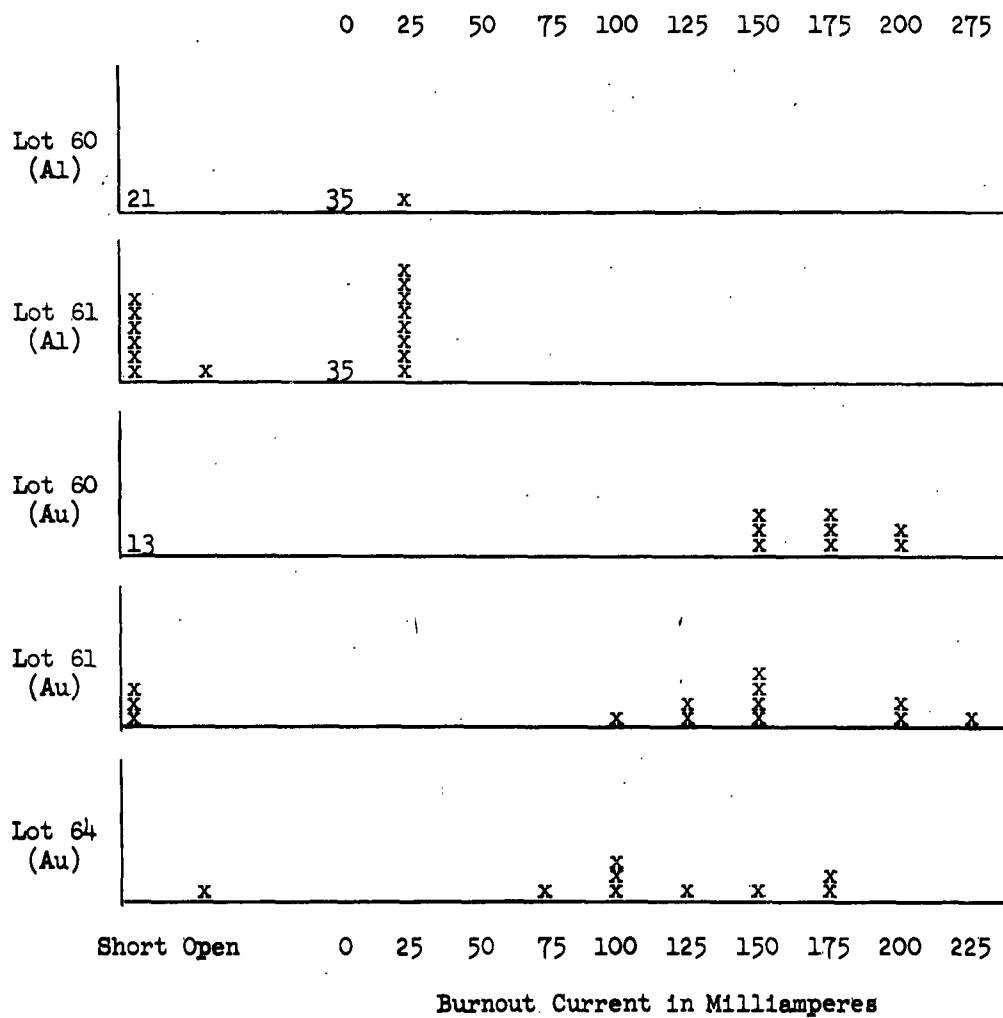
Burnout Current in Milliamperes

Figure 2

Summary of Test Results From Three Lots of Test Units

gold counterelectrodes on aluminum oxide all show about the same I-V character-
istic. One reason for the difference may be that he made his comparisons of
junction resistance at lower voltage levels than we used. Another reason may
be simply that the films are different because of some processing variable as
yet unidentified. It should be noted that Handy's data were taken on air-
grown oxide layers. Our results with gold and silver were obtained with
both thermally-grown oxides and with anodized films. Our aluminum results
were obtained with anodized films only. Our results are not considered to be
conclusive, although in most cases the data have been consistent from lot to
lot. Additional tests are planned.

F. Vacuum Conditions for Film Deposition

Pressure: A question that was of primary interest during this quarter
was whether a correlation could be shown to exist between the film current
capacity of the test units and the system pressure during deposition of the
aluminum emitter layer. No such correlation was found. In fact, out of the
three lots that are the most directly comparable, the best performance was
obtained with the lot having the emitter layer deposited under the poorest
vacuum conditions. The results are summarized in Figure 2 and Table I.

Figure 2 has already been explained. Table I shows the vacuum system
pressure before we started to heat the aluminum source, the highest value of
the pressure reading during aluminum deposition, and the pressure at the end
of the deposition process, i.e., the pressure at which the atoms forming the
surface of the emitter layer were deposited. These three pressure readings
are also shown multiplied by the deposition time. This product is proportional
to the ratio of the system pressure to the partial pressure of the depositing
aluminum and may be more meaningful than the system pressure itself. (The
amount of aluminum deposited was very nearly the same in all three lots; hence
the rate of arrival of aluminum atoms was inversely proportional to the dep-
osition time).

These and other tests led to the conclusion that, at least with our
present techniques, the electrical test results showed no meaningful correlation
with the measured pressures associated with the deposition of the aluminum

Lot No.	System Pressure			Deposition Time Seconds	Time x Pressure		
	Initial	Peak	Final		Initial	Peak	Final
60	4	80	30	120	500	10,000	3,600
61	400	1,000	1,000	40	16,000	40,000	40,000
64	60	400	-	20	1,200	8,000	-

Note: All pressures are recorded in units of 10^{-9} torr.

TABLE I

Vacuum System Pressure for Deposition of Aluminum Emitter Film

emitter film. On the other hand, our new vacuum system gave us consistently better units than were obtainable with the old system. Units with gold accelerators gave repeatably high currents, and the small number of good aluminum units gave much higher currents than had been obtained at any time during the first quarter. As already stated, we conclude that our higher pumping speed and complete system bakeout are giving us a cleaner vacuum than was obtainable before, and that this factor is more important than the total system pressure during aluminum deposition.

Use of Oil Diffusion Pump System: Although we had long since demonstrated that the aluminum emitter layer must be deposited in an oil-free environment, no data existed to indicate whether this kind of care is necessary after the preparation of the insulating film is complete. Several tests were made to answer this question.

One comparison is shown in Figure 2. Lots 60 and 61 were prepared in the ion system; the gold accelerator films of lot 64 were deposited in an oil-diffusion system. In this comparison the first two lots are superior from from the standpoint of the tunneling current of the good units, and the third lot shows the fewest open or shorted units.

A second comparison is shown in Figure 3. The test areas in lots 62 and 63 were masked down to .040" x .002" by silicon monoxide films deposited after the aluminum emitter layer was anodized. The gold films in lot 62 were deposited in the oil system; those in lot 63, in the ion system. In this case, units processed in the oil system were superior to thos processed in the ion system.

Actually, both lots were exposed to the oil system because the silicon monoxide source was set-up in that system. However, the slides in lot 63 were given a week-end bakeout (60 hours, 100 C) in the ion system just before the gold deposition. This was believed to be adequate to remove any traces of oil present on the surface of the slide. The vapor pressure of the oil is about a micron at 100 C.
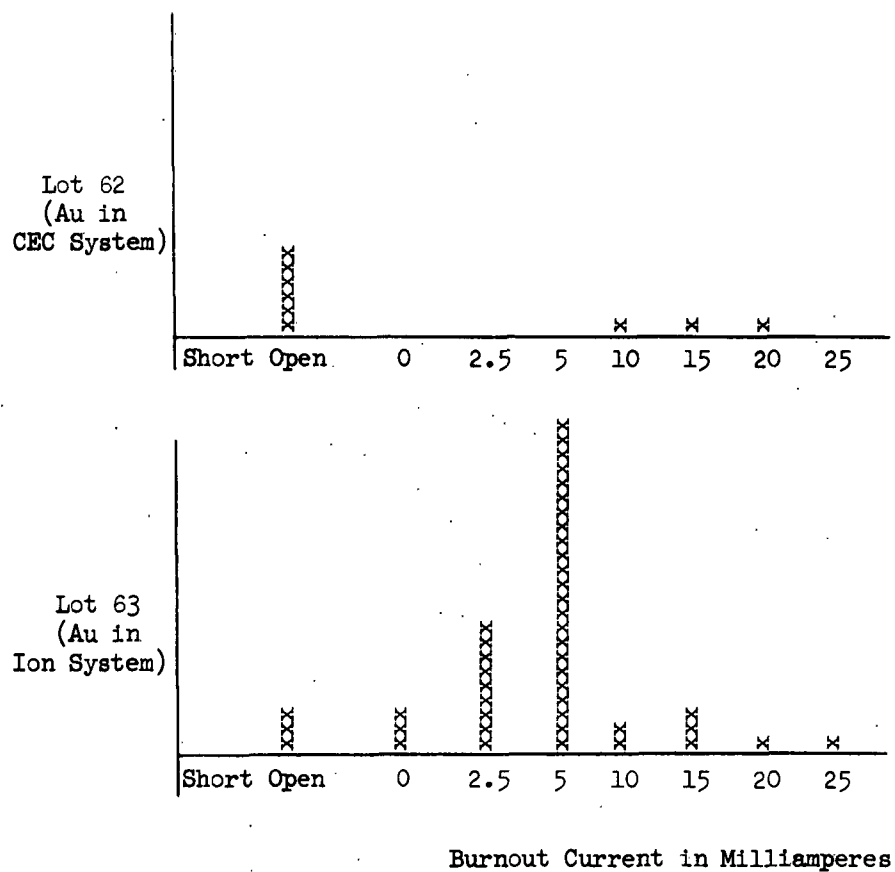
Figure 3

Summary of Test Results With Small Junction Areas

In comparing these current densities with data from other lots, note that the junction area for these units is approximately 1/20 sq. mm. rather than the usual 1 sq. mm.

The second quarter data failed to establish that oil must be completely avoided in order to produce good test units. The indication was that if any contamination problem resulted from deposition of gold accelerator layers in an oil-diffusion-pump system, it was not a serious one.

New Aluminum Source: One of the specific suggestions made by Dr. C. A. Mead, California Institute of Technology, during our visit to the west coast was that we replace our present aluminum source (Figure 6, page 15, First Quarterly Report) by a tungsten wire. Our earlier source was a boat made from .005" tantalum sheet. These boats were eaten through after several cycles of operation, usually as a result of the accumulation of aluminum near the ends of the boat, where the temperature is high enough for the aluminum-tantalum reaction to occur but low enough that the aluminum does not evaporate rapidly.
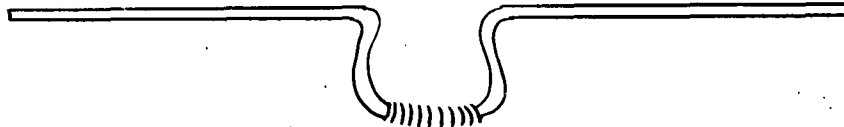
Figure 4

Tungsten Wire Aluminum Source

The new source is very simple, as is shown in Figure 4. A tungsten wire .040" in diameter is bent approximately as shown; and, if desired, a ten mil wire is wrapped around it. One or more short aluminum hairpins are draped over the tungsten loop. The wire is brought up to temperature carefully, so that as the aluminum melts it has a chance to wet the tungsten and flow onto the wire before it becomes too fluid. The .010" wire, by offering additional surface area, increases the amount of aluminum that can be held and also seems to make it easier for the aluminum to wet the tungsten initially. During operation, the hottest parts of the wire are the two sharp bends. Consequently, any aluminum that crawls up the sides of the loop is evaporated rapidly; and the aluminum is limited to the center of the loop. Attack of the tungsten occurs but is limited by the amount of tungsten the aluminum can dissolve.

We started the use of this source with lot 64 and found it quite successful. The shape of the wire is not critical, and good results were obtained both with and without the .010" wire overlay. The source becomes brittle and usually breaks when changed (as when it is removed to permit placing a gold source between the same electrodes); but, if it is not changed, fresh aluminum may be added as needed and the source is good for many cycles. Because it is small, the amount of heat generated is held to a minimum; and outgassing is therefore a less serious problem.

G. Effect of Substrate Temperature

Several attempts to measure the effect of substrate temperature during deposition of the aluminum emitter layer on glass microscope slides have failed to show any prominent effect. Figure 5 shows data obtained with $Al-Al_2O_3-Au$ units. Lots 70-73 were processed together to minimize lot-to-lot variations. To avoid unequal lengths of exposure to oxidizing atmospheres, the slides were stored in the vacuum system until the emitter layers for all four lots had been deposited. Slide 1 of each of the four lots was anodized, and these four slides were then put in the oil system at the same time for deposition of the gold accelerator film.

Test results showed all eighty units initially operable. A few were burned out to obtain the data shown in Figure 5. The remainder were saved for emission testing. The results suggest that the 150 C substrate temperature had a detrimental effect on current-carrying capacity. Otherwise, no effect is noted. Other tests made during this quarter showed no clear pattern of temperature effects, but these tests were not as well controlled as the one just described. A repeat of this test should be made to determine whether the variation noted is due to substrate temperature or to some spurious effect.

H. Effect of Reduced Test Area

During this quarter a mask was made to permit reduction of the active area of the metal-insulator-metal sandwich by the evaporation of a layer of silicon monoxide. The SiO layer is deposited after the insulating layer has been formed on the emitter film and before the accelerator film is deposited. Effectively, its function is to increase the thickness of the insulating film so that
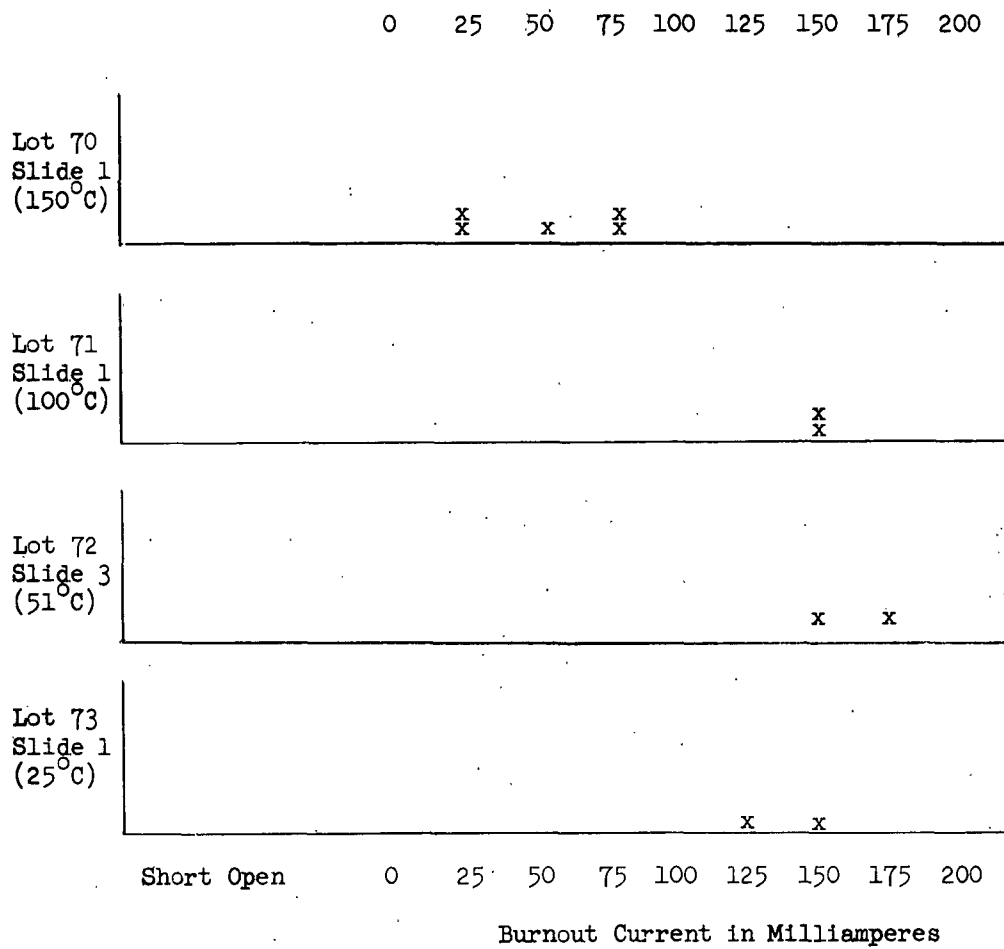
Figure 5

Summary of Lot 70-73 Test Results as a Function of Substrate
Temperature during Emitter Deposition

the tunneling current density is reduced to a negligible value. The SiO mask consists of a frame for supporting a series of wires, each wire being centered over an aluminum emitter strip (.002" diameter wire was used in the first test). Film current flows only in the area corresponding to the shadow of these wires. The resulting geometry is indicated in Figure 6 which shows a portion of an emitter film with two accelerator films crossing it. The effective area of each junction is .002" x .040".

Figure 3 shows the test results on two lots prepared in this manner. The current density at burnout was about 50 amps/cm^2 for the best unit of lot 63. This is approximately twice that obtained for the best comparable units made without the SiO masking. This tends to support our belief that burnout of the better units is a large area thermal effect, resulting from the temperature rise of the entire junction area due to its power dissipation. With the smaller junction area and the resulting reduction of total power, a higher power density is required to reach a given temperature.

The I-V characteristics of these units are quite rounded, in contrast to the sharp knee usually found in the characteristic at the point where film current starts to become appreciable. This suggests a variation in the thickness of the insulating film so that film current starts to flow at different voltages at different points on the film. Microscopic examination of the units show the edges of the SiO film to be quite sharp compared to the .002" width of the active area. However, the variations in thickness required to produce rounding of the knee are far below the range of visibility. Scattering or surface migration of a small percentage of the SiO deposited may account for the observed effect.

I. Emission Testing

A few emission tests conducted late in the quarter showed the emission, if present, to be less than the stray pickup current in the test circuit. Attempts to increase the sensitivity of the circuit were not made, because emission currents smaller than the minimum detectable level were not felt to be of immediate interest to us. Instead, units have been placed in tubes containing barium getters to determine whether measurable emission levels may be obtained by lowering the accelerator work function. This work is in progress and will be continued in the third quarter.
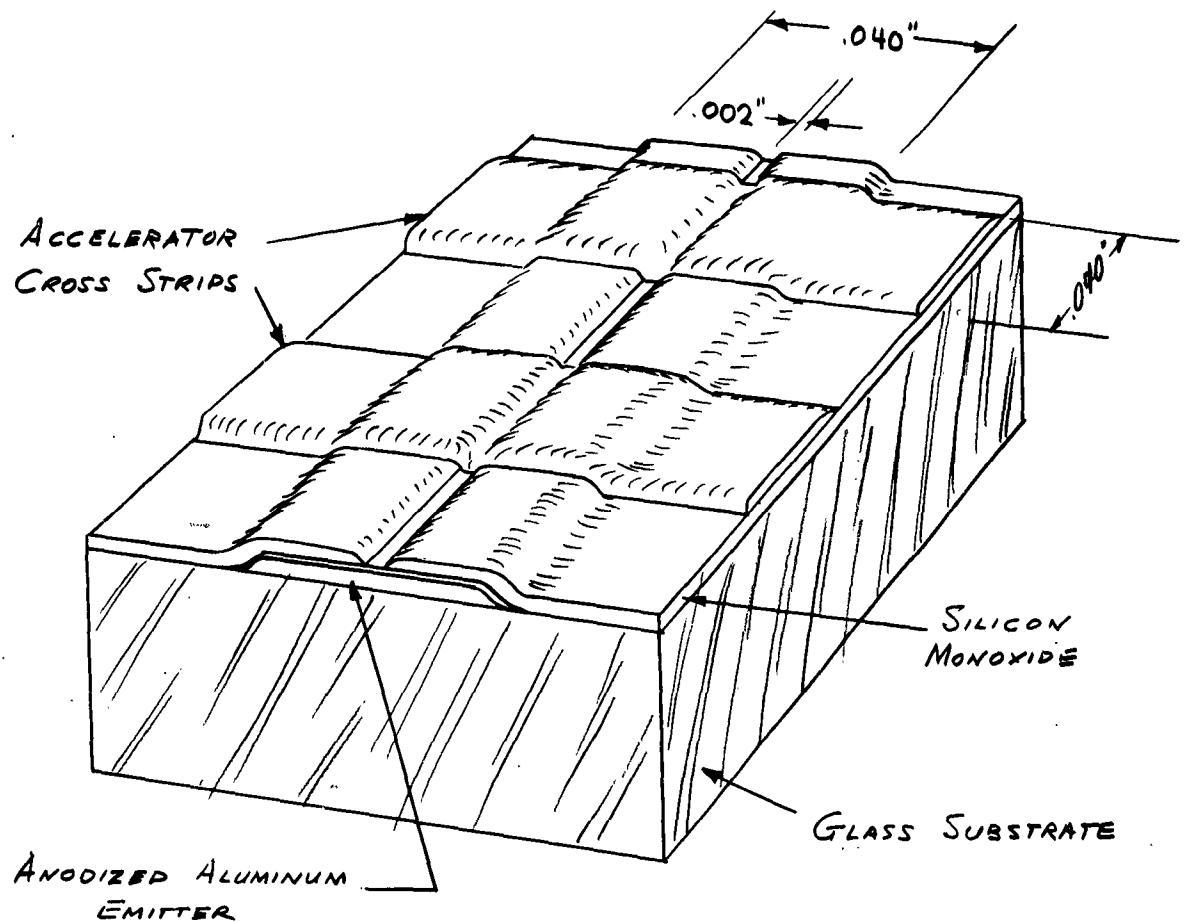
Figure 6

Schematic Drawing Showing
Silicon Monoxide Masking for Reduction of Test Area

J. Summary and Conclusions

Many of the films tested during this quarter showed burnout currents of the order of 200 ma, or 20 amps/cm^2. The limited sensitivity of the film current to such variables as substrate temperature, system pressure, and anodizing current suggests that film current may be limited by thermal considerations and may no longer be a good criterion of film quality. The fact that masking down the junction area permits higher current densities supports the point of view

that all of the better films will burn out at a particular temperature. Measurement of further improvements in film quality must be based on more sensitive methods.

At least four methods exist for making measurements that should be more sensitive to variations in film quality. The most direct is the measurement of emission current, and much greater emphasis on obtaining this type of information is planned for the next quarter. The other three methods involve minimizing the thermal problems, and are (1) the use of smaller junction areas as just described in section H, (2) pulse testing, using the circuit described in the first quarterly report, and (3) the use of metallic or other high-conductivity substrates for heat sinking.

At least with our present films and techniques, gold is the best accelerator material tried to date. Both aluminum and silver show evidence of penetration or damage to the insulating film. Silver is apparently less harmful to anodized films that to air-grown or thermally-oxidized films, but data on this point are not conclusive.

Variations in anodizing current density have not been shown to have any effect. In making the electrical measurements, we got the impression that the lowest current density yielded poorer films; but we were not able to find convincing support for this opinion in the recorded data.

Both anodized and thermally-oxidized films have good electrical properties. As would be expected, the test results suggest a more uniform thickness for the anodized films.

Results are to date insensitive to substrate temperature during emitter deposition at temperatures below 100 C. A substrate temperature of 150 C appears to give poorer results than are obtained at 100 C and below.

Probably the most important accomplishment of this quarter is the discovery that good units, at least from the standpoint of the current-carrying capacity of the insulating films, may be made consistently by the use of gold accelerator films and proper attention to vacuum conditions during deposition of the aluminum emitter film. The required vacuum conditions seem to be primarily a function of cleanness rather than low pressure.

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